Set-Based Method in Early Stage Naval Ship Design

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Agenda

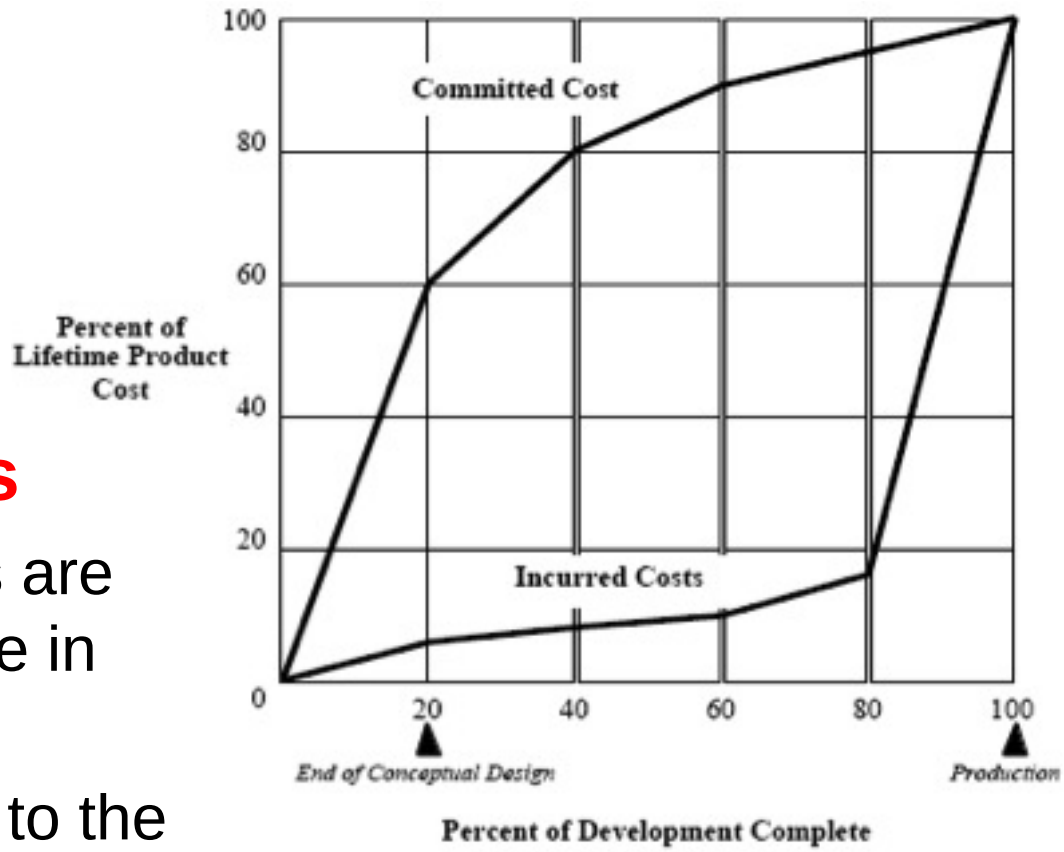
- Problems Associated With Design
- Point-Based Design
- Toyota Design Process
- Set-Based Design
- Point-Based vs. Set-Based Design
- Other Methods
- Example

Source:
What is Set-Based Design?
David J. Singer, PhD., Captain Norbert Doerry, PhD., and Michael E. Buckley
To be presented ASNE Day 2009

Design Methods in the Aerospace Industry: Looking for Evidence of Set-Based Practices

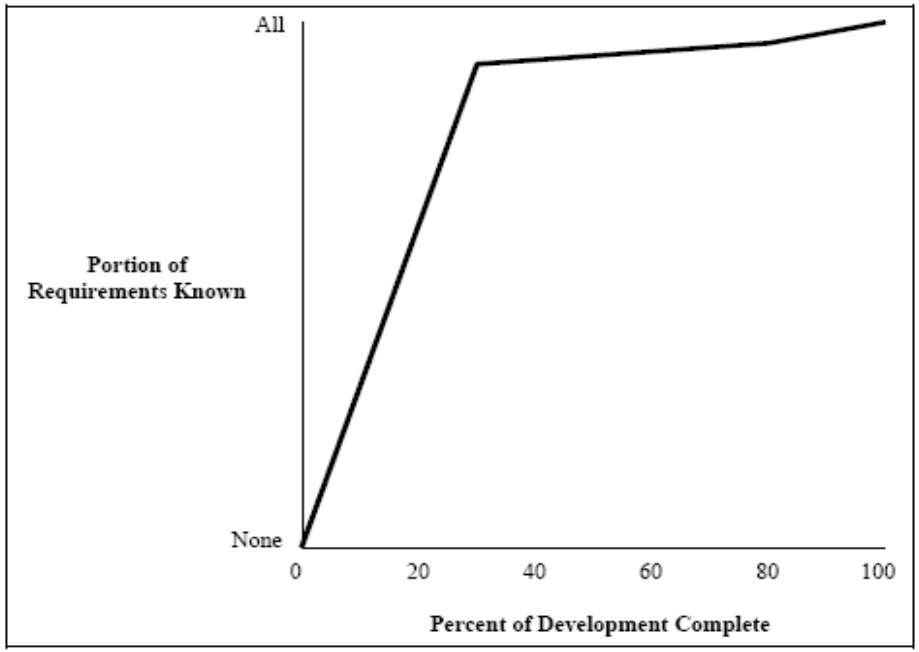
Joshua I. Bernstein
Master of Engineering Aeronautics and Astronautics
Massachusetts Institute of Technology, 1997

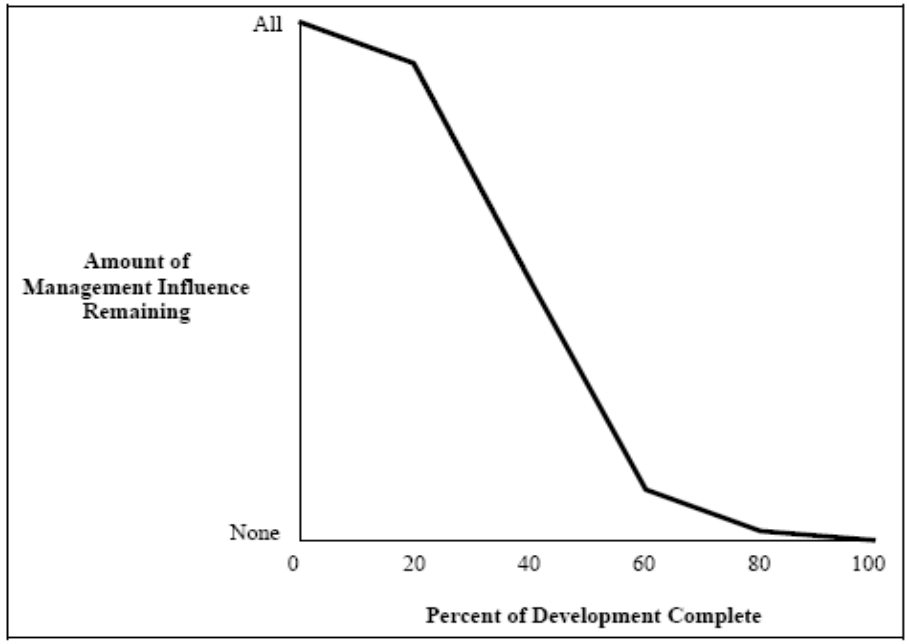
Problem 1: Cost Profile During Design



- **Designing-in costs**
  - Majority of the costs are not incurred until late in program
  - Cost are committed to the product's lifecycle very early

Problem 2: Requirements Understanding During Design vs. Influence / Impact on Cost



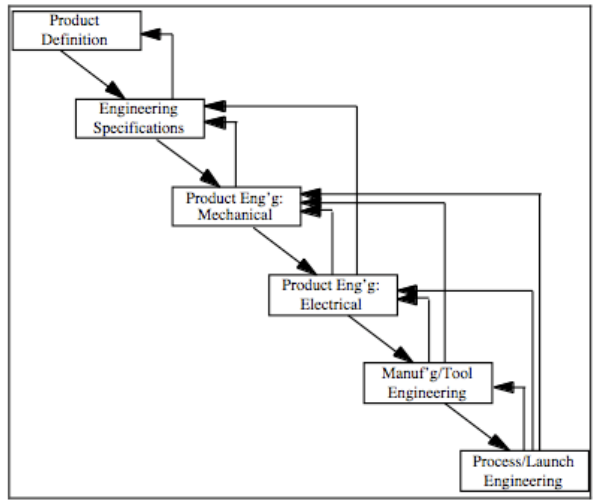


Problem 3: Knowledge Requirements

- Ship design requires both objective knowledge (mathematical models) and subjective knowledge (expert opinion)
  - Objective and subjective knowledge require domain experts
  - In real world domain experts are not collocated
  - Subjective knowledge is the hedge against uncertainty

Point-Based Design Strategies

Typical design processes can be characterized as point-based or iterative approaches: They seek to develop and select a single concept, i.e., a single point in the design space, as quickly as possible. In general, point-based strategies consist of five basic steps (Liker et al.)



1. First, the problem is defined.
2. Once the problem is clearly stated, engineers and designers generate a large number of alternative design concepts, usually through individual or group brainstorming sessions.
3. Engineers then conduct preliminary analyses on the alternatives, leading to the selection of a single concept for further development.
4. The remaining concept is then further analyzed and modified until all of the product's goals and requirements are met.
5. If the selected concept fails to meet the stated goals, the process begins again, either from step 1 or 2, until a solution is found.

Due to computational intensity of "advanced" tools a point-based approach is often taken so that those tools can be used during the design process.

Point-Based Design in Concurrent Engineering Environment

- Although concurrent engineering and IPTs have dramatically changed (and improved) engineering design, they have not significantly altered the nature of the design process.
- Non-CE methods were typified by one engineering group throwing a design over the wall to another group.
- What CE and IPTs have done is to “lower the wall:”
  - Upstream design groups now receive quick and extensive input and feedback on their design decisions from downstream organizations. But within the team the nature of the design process has not changed:
    - one group or person establishes requirements, another proposes a design solution, several others make comments about and recommend changes to the solution, etc. (Liker et al., p. 165).

The Toyota Product Development System

- The Toyota Product Development System: Integrating People, Process, and Technology
  - By James Morgan and Jeffrey Liker
- Lean Product Development System Model Principles
  1. Establish Customer Defined Value to remove waste
  2. **Front-Load the Product Development Process to Explore Thoroughly Alternative Solutions while there is Maximum design space**
  3. Create a Leveled Product Development Process Flow
  4. **Utilize Rigorous Standardization to Reduce Variation, and Create Flexible and Predictable Outcomes**
  5. Develop a Chief Engineer System to Integrate Development from Start to Finish
  6. **Organize to Balance Functional Expertise and Cross-Functional Integration**
  7. **Develop Towering Technical Competence in all Engineers**
  8. Fully Integrate Suppliers into the Product Development System
  9. Build in Learning and Continuous Improvement
  10. Build a Culture to Support Excellence and Relentless Improvement
  11. **Adapt Technology to Fit Your People and Process**
  12. Align your Organization through Simple, Visual Communication
  13. Use Powerful Tools for Standardization and Organizational Learning

Set-Based Design

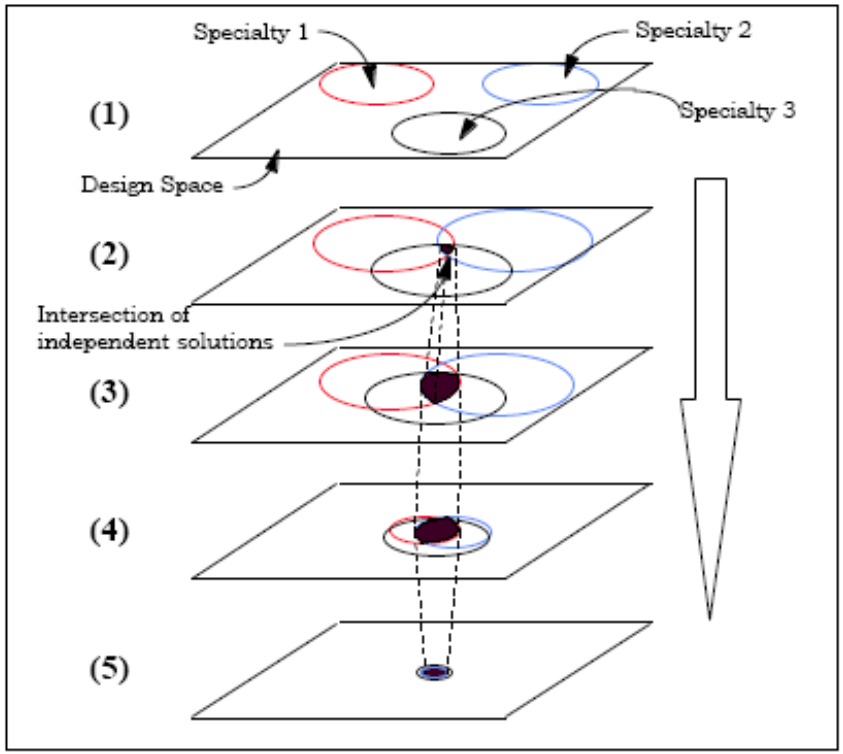
- *The Second Toyota Paradox: How Delaying Decisions Can Make Better Cars Faster*
  - *Ward, Liker, Cristiano, Sobek*
  - How is it that Toyota delays critical decisions yet their designs come to market faster and better.
- The main features of set-based design process include:
  - broad sets for design parameters are defined to allow concurrent design to begin,
  - these sets are kept open longer than typical to more fully define tradeoff information,
  - the sets are gradually narrowed until a more globally optimum solution is revealed and refined.

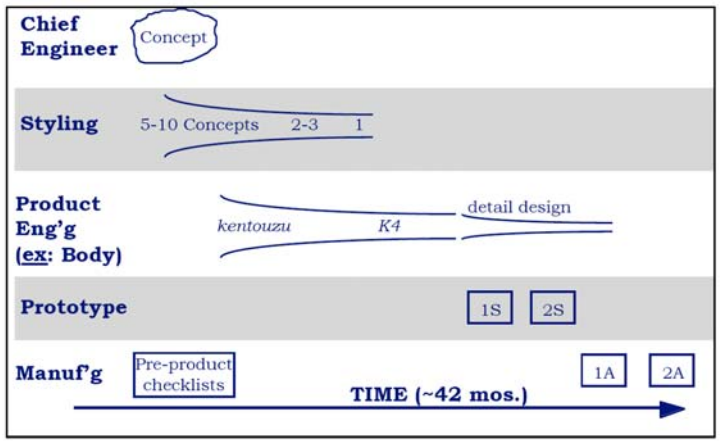
SBD Process

Understand the design space
- Define feasible regions
- Explore tradeoffs by designing multiple alternatives
- Communicate sets of possibilities

Integrate by intersection
- Look for intersections of feasible sets
- Impose minimum (maximum) constraint
- Seek conceptual robustness

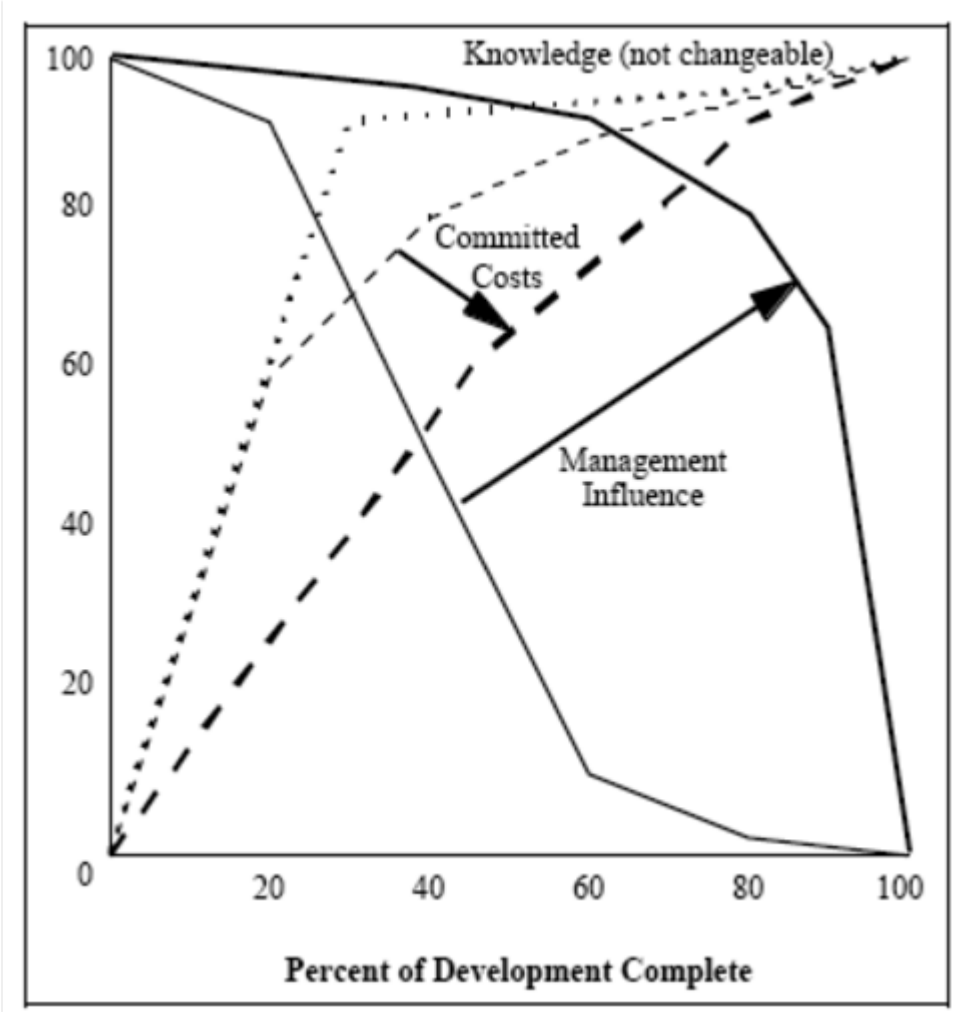
Establish feasibility before commitment
- Narrow sets gradually while increasing detail
- Stay within set once committed
- Control by managing uncertainty at process gates





Advantages of Set-Based Design

- Provide mechanism to allow managers and engineers to delay decisions while at the same time continuing to develop a product.
- The goal is to increase managements influence late in the development process by delaying the commitment of costs.



Point-Based vs. Set-Based

Function	Point-Based Approach	Set-Based Approach
Search: How should solutions be found?	Iterate on existing ideas. Brainstorm new ideas.	Define feasible regions.
Communication: Which ideas are communicated to others?	Communicate the best idea.	Communicate sets of possibilities.
Integration: How should the system by integrated?	Pass the idea among the team for critique.	Look for intersections.
Selection: How is the best idea identified?	Formal schemes for selecting the best alternative. Make prototypes to confirm that the solution works.	Design in parallel on each alternative until it is not worth pursuing. Look for low cost test to prove infeasibility.

Point-Based vs. Set-Based

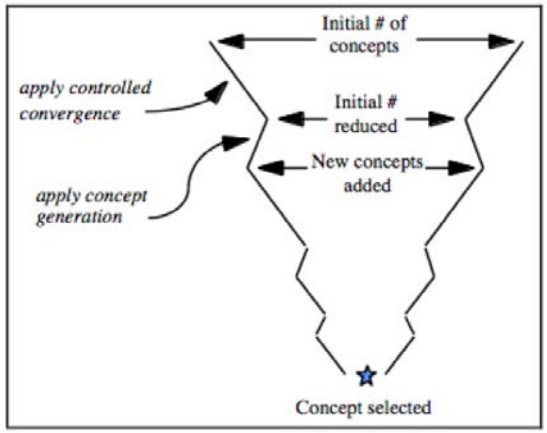
Function	Point-Based Approach	Set-Based Approach
Optimization: How should the design be optimized?	Analyze and test the design. Modify the design as necessary to achieve objectives and improve performance.	Design in parallel on each alternative until not worth pursuing. Look for low cost test to prove infeasibility.
Specification: How should you constrain others with respect to your own subsystem design?	Maximize constraints in specifications to assure functionality and interface fit.	Use minimum control specifications to allow optimization and mutual adjustment.
Decision Risk Control: How should one minimize the risk of "going down the wrong path?"	Establish feedback channels. Communicate often. Respond quickly to changes.	Establish feasibility before commitment. Pursue high-risk and conservative options in parallel. Seek solutions robust to physical, market, and design variation.
Rework risk control: How should one minimize damage from unreliable communications? Management: How should the process be controlled?	Establish feedback channels. Communicate often. Respond quickly to changes. Review designs and manage information at transition points.	Stay within sets once committed. Manage uncertainty at process gates.

Which Method to Use?

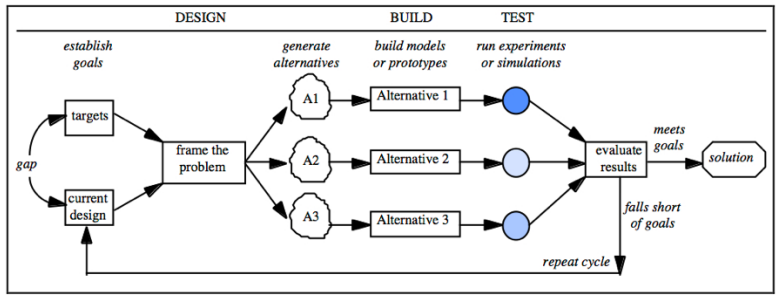
Table 6: Criteria for selecting between set-based and point-based design strategies.

If the development project is characterized by:	*Then apply:*
• A large number of design variables • Tight coupling between design variables • Conflicting requirements • Flexibility in requirements allowing for design trades • Technologies and design problems which are not well understood, and, consequently, require rapid learning	Set-based techniques
• Requirements for specific technologies • Requirements to optimize the design along only one or two dimensions or parameters • Well-understood technologies or design problems	Point-based techniques

Other Methods



Method of Controlled Convergence

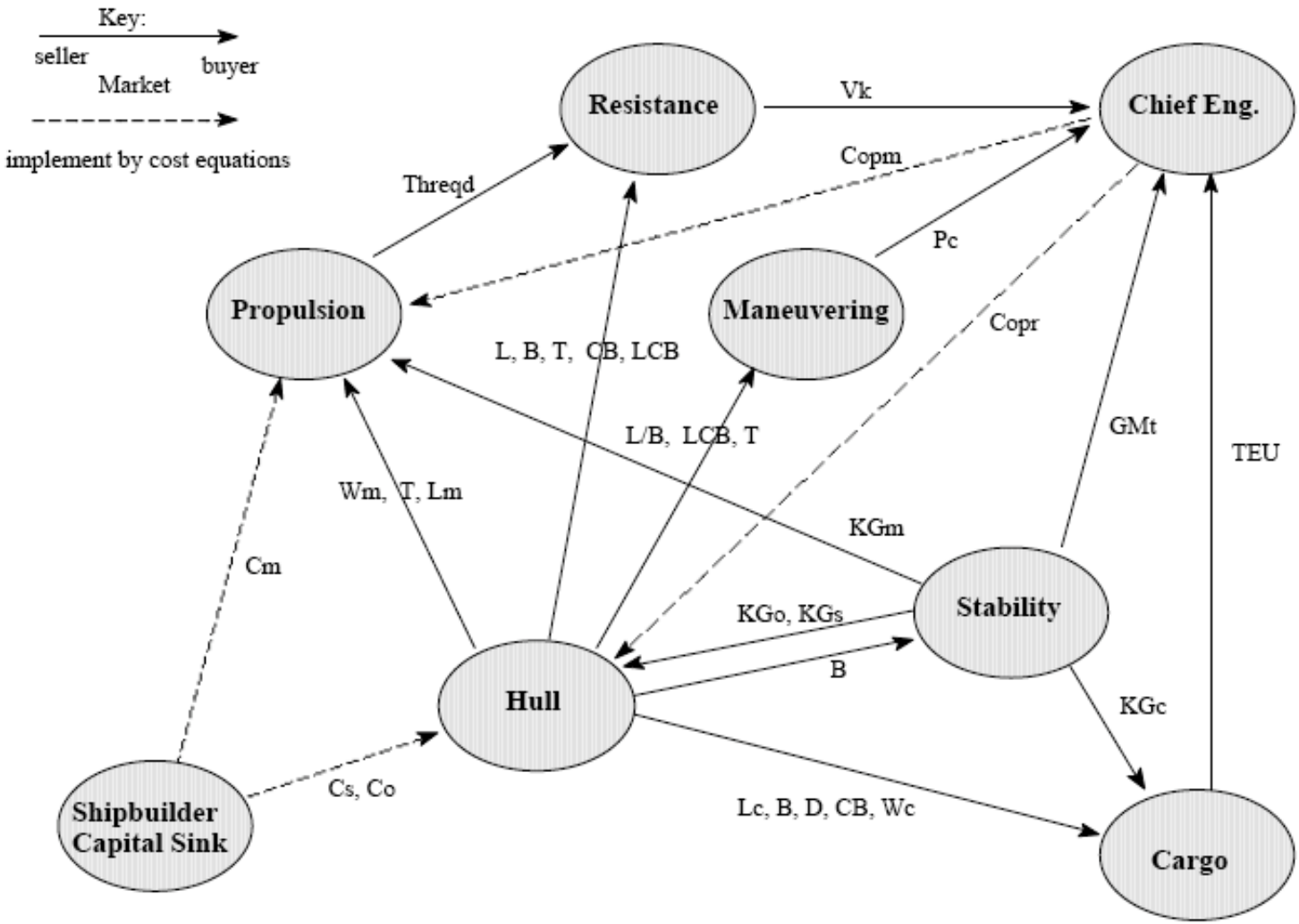


The design-build-test cycle

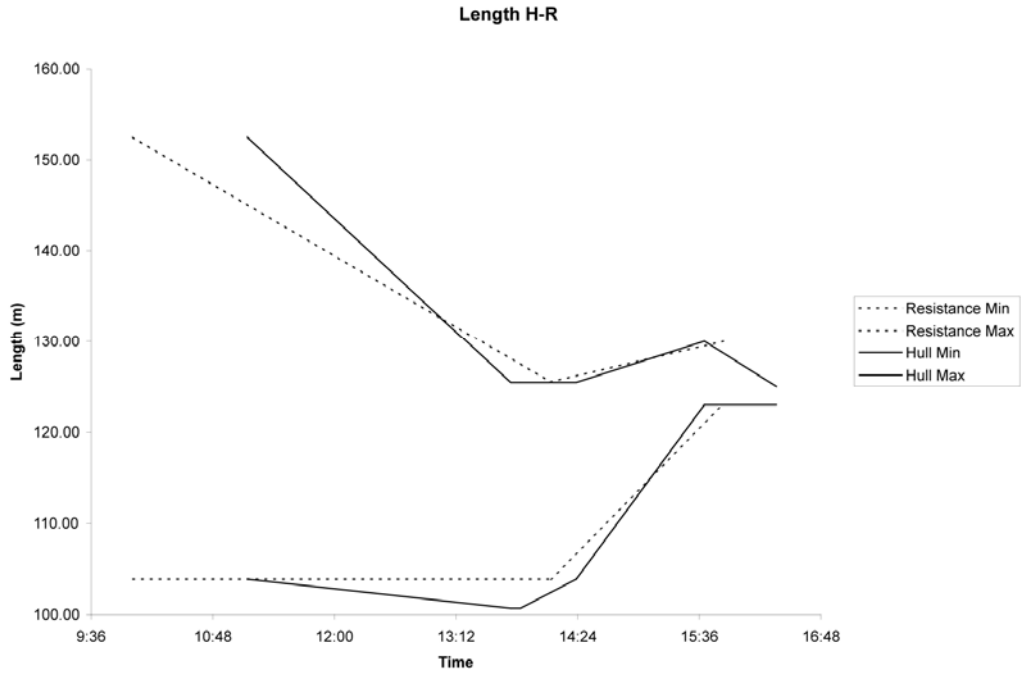
What is the Difference?

- The way in which options are used!
  - In MCC and DBT alternatives are created and evaluated to better understand how different design parameters, or configurations, impact the concepts ability to satisfy a user requirement
  - set-based methods also use options to allow each specialty group working on a product to explore the design space independently. By allowing specialty groups to independently analyze their design options, set-based methods eliminate the iterative paths that can be so problematic in point-based approaches. Controlled convergence and design-build-test do not necessarily emphasize this use of design options

Containership SBD Example



SBC Convergence Example



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6x6+2	6	6	2	19.6	15.14			500	600			
6x6+3	6	6	3	19.6	15.14			580	696			
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Conclusion

- The set-based design paradigm can replace point based design construction with design discovery; it allows more of design to proceed concurrently and defers detailed specifications until tradeoffs are more fully understood.